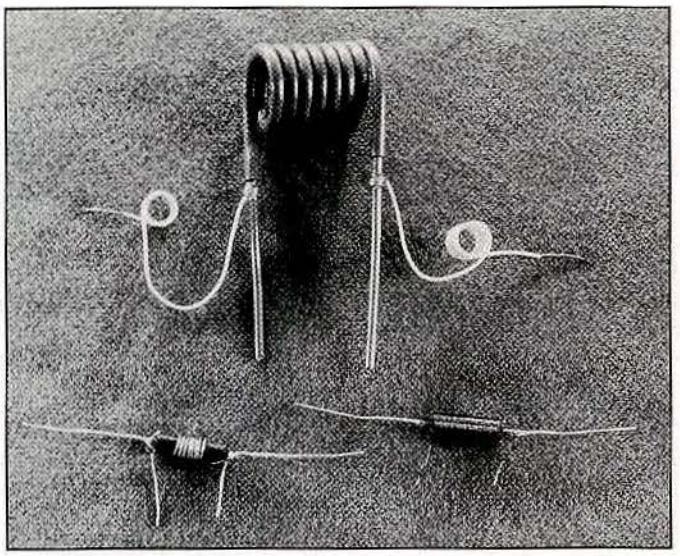
By Dean F. Poeth II, K8TM

How to Measure Large Direct Currents with Common Meters

Multimeters and panel meters seldom measure more than 10 A. *Sense* resistors and meter shunts can help—for pennies apiece!

Current measurements within a circuit can be frustrating! Most multimeters only measure up to 1 A, while many 12-V circuits draw substantially more. Even a 2-meter radio can draw several amperes. Fortunately, there are several simple ways to solve this problem.



Use Voltage Drops to Measure Current

There are several ways to measure current. One of the easiest methods is to measure the voltage drop across a small resistance.[1] See Figure 1. The same current flows through the load resistor, R_L, and the current measuring resistor, R_M. By making the resistance of R_M much less (less than 10%) than that of R_L, R_M will have a negligible effect on the circuit. [Many circuits contain resistors that can function as R_M. See the sidebar "Looking for R_M"—*Ed.*]

Ohm's Law says that the current passing through R_M will generate a small voltage drop, V_R, which is proportional to the current flowing to the load. Therefore, we can use V_R to calculate the current flowing through R_L.

Figure 2 shows a practical application of this concept. BT_1 is a car battery, R_L is a car taillight bulb, and R_M is a 0.01-Ω resistor. The current flowing through this circuit generates a voltage drop across R_M that you can measure with a digital voltmeter. The internal resistance of the voltmeter is so high that it has practically no effect on the circuit.

If the light bulb draws 1 A, the voltage across R_M will be 0.01 V (10 mV) from Ohm's Law:

$0.01\ \Omega \times 1\ A = 0.01\ V$

Similarly, if the load draws 5 A, 0.05 V will appear across R_M.

By thoughtfully selecting the resistance for R_M, you can make a digital voltmeter directly indicate the current flowing through the load.

Make Your Own Voltage-Drop Resistors

Making R_M is probably much easier than you think. Furthermore, they only cost a few pennies each!

We make R_M from a length of wire with known resistance, as shown in Figure 3. All wire (even the best) has resistance, and here we use this property to make a resistor. The voltage is measured across a specific wire length, L_M, so that its resistance is a convenient value. R_M (wire) has two *sense* wires soldered to it as shown. The current flows through the large wire and the sense wires connect to a voltmeter.

For example, suppose you need to measure the current going to a load (say a 2-meter transceiver) that draws 5 A from a 12-V power supply.

First, determine the maximum current the resistor wire must carry. Since we expect our load to draw 5 A, we must select a wire that can safely handle this amount of current. The current demand determines the wire gauge for the resistor.

Next, go to a copper-wire table (like the one on page 24.8 of the 1996 *ARRL Handbook*) and select the smallest wire that can safely conduct at least this amount of current. (For this application 100 circular mils/ampere, cmil/A, is sufficient.) For our example, #22 enameled copper wire should be more than adequate, and it's available at the corner electronics store (Radio Shack). It's a good idea to select a wire of slightly greater current capacity than you need. Remember, *heavier* wires have larger di-

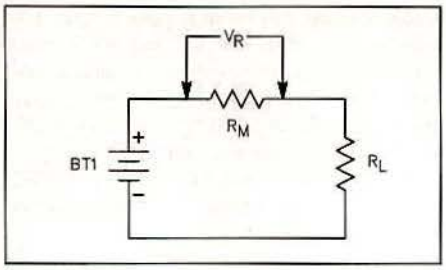


Figure 1—We want to measure the current through a load, R_L. We can do so by inserting a known resistance, R_M, in series with R_L, measuring the voltage across R_M and using Ohm's Law to calculate the current. R_M should have much less resistance (less than 10%) than R_L.

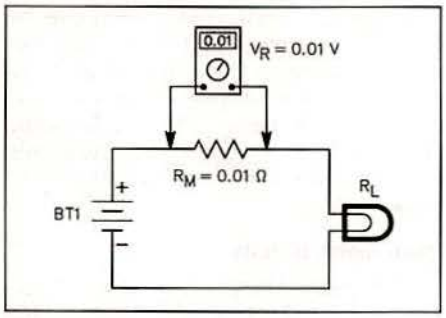


Figure 2—A practical application uses a 0.01-Ω R_M to measure current through a taillight bulb, R_L, provided by an automotive battery, BT_1.

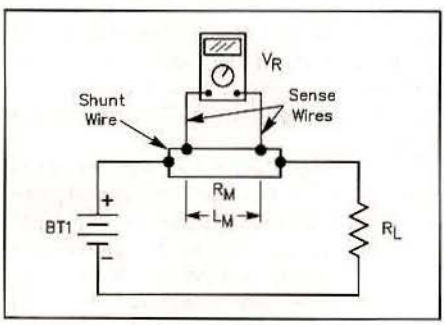


Figure 3—While the wire length of R_M is somewhat longer than L_M, V_R is measured only across L_M (between the sense wires).

ameters and greater current capacities, but *smaller* wire-gauge numbers.

In this example, we want a 5-A current to generate 0.05 V across R_M. Use Ohm's Law and the wire table to determine how long the #22 wire must be in order to drop 0.05 V at 5 A:

$$R_M = \frac{E}{I} = \frac{0.05\,V}{5\,A} = 0.01\,\Omega$$

From the wire table, 1000 feet of #22 copper wire has 16.2 Ω of resistance.

To find the L_M of #22 wire, use this equation:

$$L_M = \frac{R_M}{\left(\frac{X\,\Omega}{1000\,ft}\right)} = \frac{0.01\,\Omega}{\left(\frac{16.2\,\Omega}{1000\,ft}\right)} = 0.617\,ft$$

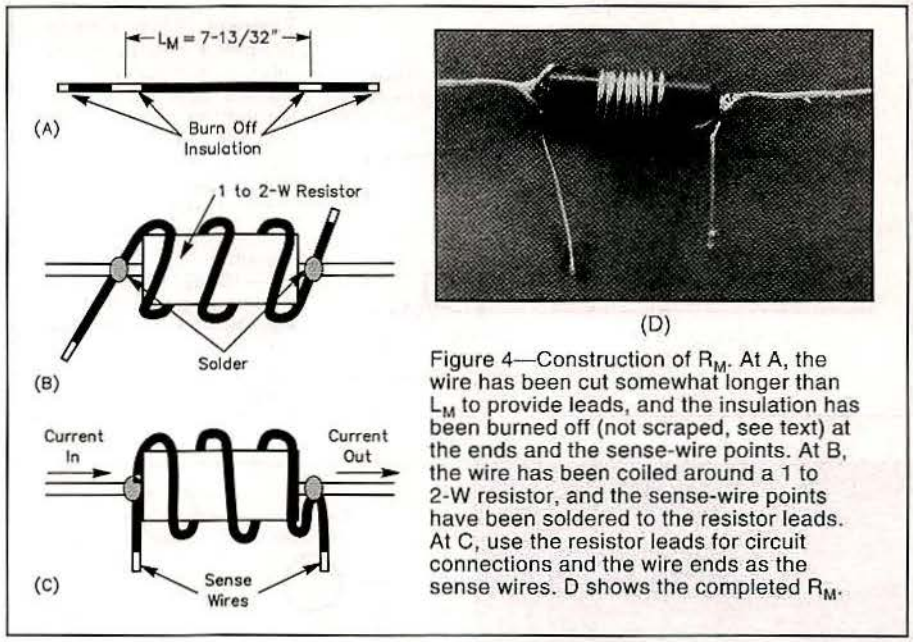


Figure 4—Construction of R_M. At A, the wire has been cut somewhat longer than L_M to provide leads, and the insulation has been burned off (not scraped, see text) at the ends and the sense-wire points. At B, the wire has been coiled around a 1 to 2-W resistor, and the sense-wire points have been soldered to the resistor leads. At C, use the resistor leads for circuit connections and the wire ends as the sense wires. D shows the completed R_M.

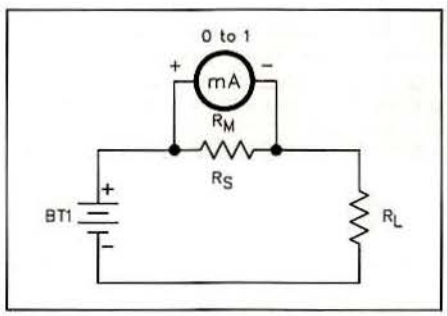


Figure 5—A meter *shunt* resistor, R_S, expands the range of a 0 to 1-mA meter. Because R_M/R_S, is a set ratio, the current through the meter is a known proportion of the current through R_L.

The final length between the sense wires should be $7^{13}/_{32}$ inches.

Cut a piece of #22 low-temperature enameled wire a few inches longer than this. Using a hot soldering iron, burn off a $^1/_8$-inch section of the enamel insulation 1 inch from one end. (See Figure 4.) Do not *scrape* off the insulation, as this can decrease the wire's cross section (and increases its resistance) slightly. Solder this section to the lead of a 1 or 2-W resistor as shown. The resistor can have any value above 1 kΩ, because we are using it only as a convenient form for the wire. Now carefully measure $7^{13}/_{32}$ inches from this solder joint. Be as accurate as you can. Mark this distance and burn off a small area of insulation. Wrap the wire gently around the body of the resistor and solder the marked length to its other lead. Burn off the insulation at the ends of the wire, and you are done!

Resistors made in this way can be very accurate. My experiments have shown that, by exercising reasonable care, the accuracy is better than 5%. This is quite acceptable, considering how simple it is to make the resistor. To maximize accuracy, make the wire at least six inches long between the sense wires (longer is better) so that any errors in measurement become insignificant. Similarly, measure L_M between the sense wires accurately, and make the sense-wire connections small. Finally, try not to bend the wire sharply or repeatedly, as cold working increases its resistance slightly.

You can make a voltage-drop resistor a permanent part of any circuit. To measure the current in the circuit, simply connect a digital voltmeter to the sense wires.

Meter Shunts

The voltage-drop resistor described previously makes an excellent test device. Unfortunately, it is not a good solution where continuous current measurement is required. This is so because it requires a sensitive (and relatively expensive) voltmeter, such as a digital multimeter, to measure V_R. For permanent installations, such as an ammeter for a homebrew power supply, a surplus 0 to 1-mA analog meter is much less expensive.[2]

Connect the surplus meter as shown in Figure 5. Here R_S *shunts* most (but not all) of the current around the meter. You may use any size shunt, so long as it decreases the sensitivity of the meter by a convenient amount.

In order to make a shunt, you must first determine the internal resistance (R_M) of the meter. Unlike the digital multimeter used earlier, this meter will have a low internal resistance. Therefore, we must consider the current through the meter.

Many meters have their internal resistance printed in very small letters on the meter face or back. Inspect the meter carefully to find this printing. If the meter resistance is unknown, you can measure it by

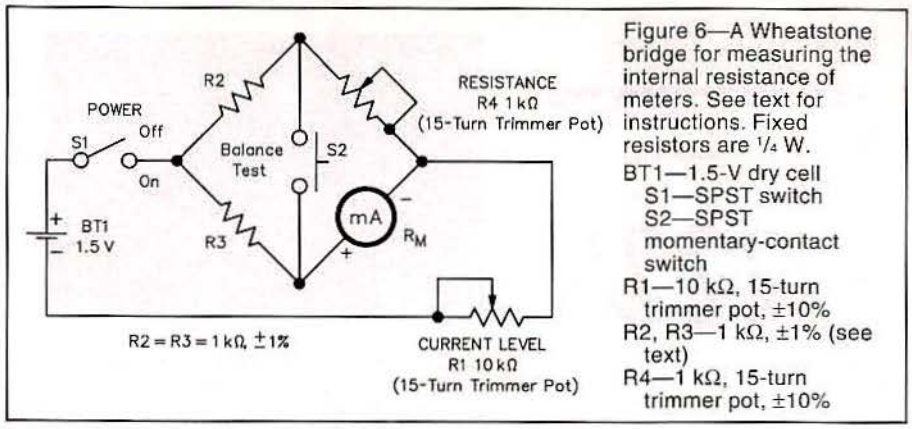


Figure 6—A Wheatstone bridge for measuring the internal resistance of meters. See text for instructions. Fixed resistors are 1/4 W.
BT1—1.5-V dry cell
S1—SPST switch
S2—SPST momentary-contact switch
R1—10 kΩ, 15-turn trimmer pot, ±10%
R2, R3—1 kΩ, ±1% (see text)
R4—1 kΩ, 15-turn trimmer pot, ±10%

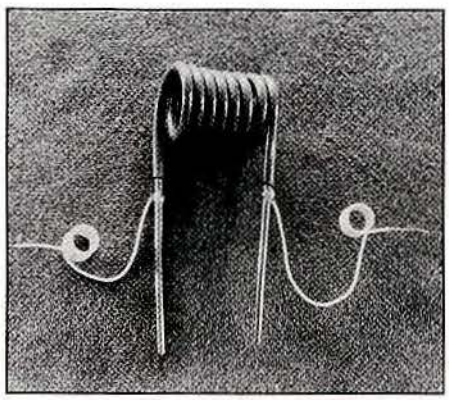


Figure 7—A completed, homebuilt meter shunt.

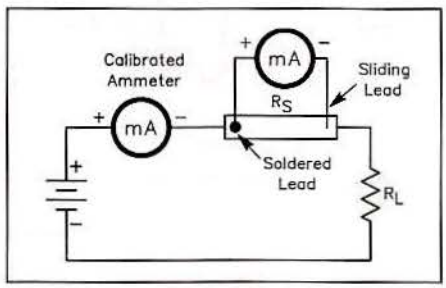


Figure 9—A setup for calibrating meter shunts. To calibrate the shunt, slide the unsoldered meter lead along the shunt until the two meters show the same value.

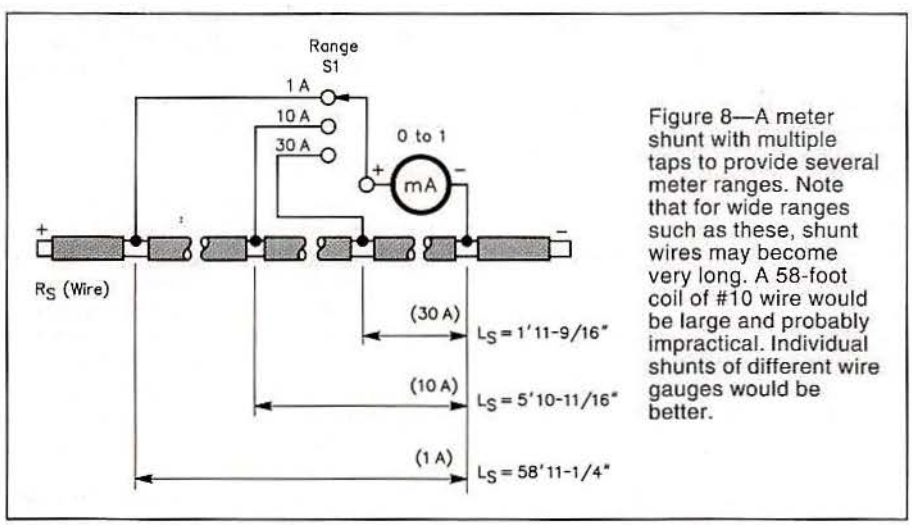


Figure 8—A meter shunt with multiple taps to provide several meter ranges. Note that for wide ranges such as these, shunt wires may become very long. A 58-foot coil of #10 wire would be large and probably impractical. Individual shunts of different wire gauges would be better.

using a *digital* multimeter set on the "ohms" position. Connect the red lead from the multimeter to the positive terminal and the black lead to the negative terminal of the meter. Never, under any circumstances, attempt to use an *analog* multimeter to measure another meter's internal resistance. These older instruments drive too much current through the meter and may damage or destroy it.

Start at the highest resistance range of the digital multimeter and work downward until you get an acceptable reading. Continuously watch the analog meter's needle to see that it does not pin against either end of the scale. Be especially careful when measuring the resistance of very sensitive meters (less than 1 mA full scale), as these are very delicate.

If you do not have a digital multimeter available, you can still measure a meter's internal resistance using a Wheatstone bridge. This technique was first used by Lord Kelvin to measure the internal resistance of galvanometers; it is known as the *Kelvin method*. Build the Wheatstone bridge circuit shown in Figure 6. Use 1% tolerance resistors for R2 and R3 if possible. If precision resistors are not available, assure that R2 and R3 are very close in value by picking two 5% tolerance resistors from the same package.

The current flowing through switch S2 is zero when the bridge is balanced. This occurs when:

$$\frac{R2}{R4} = \frac{R3}{R_M}$$

By making R2 and R3 equal, the resistance of R4 will be that of R_M when the bridge is balanced.

Connect the unknown meter to the circuit and increase R1 to maximum. Close S1 and adjust R1 until the meter needle rises to one-half scale. Now, adjust R4 until the meter needle reads the same whether S2 is open or closed. When this condition occurs, the bridge is balanced. Remove R4 from the circuit and measure its resistance with an accurate ohmmeter. This value is the resistance of R_M.

Homemade Shunts

Homemade shunts are simple, cheap, and fun! Each shunt is made from a specific length of wire with sense wires soldered to it, as illustrated in Figure 7. Begin by selecting the wire gauge that can safely conduct the current drawn by the load. Enameled wire easily dissipates heat and can be safely sized at 100 cmil/A when wound around a resistor. Heavily insulated wire (common in the larger sizes) needs more conductor area per ampere; rate it at 250 cmil/A for single wires, 700 cmil/A for bundles.

For example, suppose you need to measure the current drawn by a solid-state HF transceiver that operates from a 12-V dc power supply. Assume the radio draws 25 A on transmit, and that you have a surplus 0 to 1-mA meter graduated from 0 to 3 A. A simple solution would be to design the shunt so that the meter reads from 0 to 30 A.

Referring to *The ARRL Handbook* copper-wire table, #10 wire can safely handle 40 A, which is more than enough for this job. What's more, you can conveniently purchase it at any hardware store that sells electrical supplies.

To determine the resistance of the shunt use this equation:

$$R_S = \frac{R_M}{(n-1)}$$

where R_S is the resistance of the shunt; R_M is the resistance of the meter; and n is the shunt's multiplication factor. For our example, n = 30,000 because:

$$30{,}000 \times 0.001 \text{ A} = 30 \text{ A}$$

when using a 0 to 1-mA meter to measure 0 to 30 A.

For example, suppose that the Kelvin method shows the resistance of your meter

Looking for R_M

We can measure current by installing a separate resistor, R_M, but even though that resistor is relatively small, it *does* affect (reduce) the current in the circuit. If the value of R_M is exactly 1% of the circuit resistance, the measured current will be about 99% of the current without R_M in the circuit. Many discrete-component circuits contain resistors suitable for use as R_M. For example, emitter resistors in transistor amplifiers permit us to measure collector current. We can calculate the current from the measured voltage across the resistor. This result is as precise and accurate as the voltage and resistance measurements. These measurements require several warnings: Test leads may form unwanted feedback paths that let the circuit oscillate. RF that reaches the meter may distort the measurement. (Both of these effects may be reduced by adding a RF choke in series with the test lead near the tip.) Do not expose anyone to high voltage levels or RF radiation when making such measurements. Here's how it's done:

1. Choose a resistor that carries all of the current you want to measure.
2. Remove power from the circuit and discharge the power-supply capacitors (if the power supply remains connected to the circuit).
3. Disconnect one of the resistor leads; measure and record the resistor's resistance. (In low-current circuits you can simply cut the lead.)
4. Reconnect the lead.
5. Switch on the power and measure the voltage across the resistor.
6. Calculate the current from I = E/R.

to be 58.8 Ω. With R_M = 58.8 Ω and n = 30,000, the equation gives:

$$R_S = \frac{58.8\ \Omega}{(30{,}000-1)} = 0.00196\ \Omega$$

The resistance of #10 wire is 0.9987 Ω/1000 ft, from the copper wire table. The length of the shunt wire, L_S, is then:

$$L_S = \frac{R_S}{\left(\frac{X\ \Omega}{1000\ \text{ft}}\right)} = \frac{0.00196\ \Omega}{\left(\frac{0.9987\ \Omega}{1000\ \text{ft}}\right)} = 1.96\ \text{ft}$$

or 1 foot 11$^9/_{16}$ inches between the sense wires. Cut a length of #10 insulated wire several inches longer than that. Remove the insulation from one end of the wire using a hobby knife; be very careful not to nick the wire. Solder one sense lead here and accurately measure L_S to the other sense wire. Carefully remove the insulation there and solder the second sense wire in position. Wind the wire over a screwdriver handle and you are done!

Multiple-Range Shunts

A simple improvement of the single shunt has multiple sense wires for use at different current ranges. (See Figure 8). This type of shunt is useful for measuring the current drawn from a test-bench power supply. For example, suppose you wanted an ammeter to read 0 to1 A, 0 to 10 A and 0 to 30 A. Simply tap a 0 to 1-A shunt for the additional current ranges. (Taps for higher current ranges require *less* resistance than for the lowest current range.) Determine the L_S of wire needed for each current range and solder the sense wires in position.

Calibration

You can calibrate either of these shunts using a calibrated meter. Simply connect the homemade shunt to a test circuit like the one in Figure 9. Be sure that R_L can safely dissipate the amount of power flowing through the circuit. I have found that car taillight bulbs work very well for R_L.

Solder the first sense wire in position and remove the insulation from where the second sense wire should go. Connect the shunt to the test circuit and slide the second sense wire up or down the shunt until both the calibrated ammeter and the shunt meter agree. Mark the position for the second sense wire and remove power from the circuit. Solder the second sense wire into position to finish the job. It's a good idea to recheck the calibration after soldering.

Conclusion

Making these current-measurement tools is fun, quick and inexpensive. The result is a device that can have surprising accuracy and can solve many current-measurement problems. So the next time you have trouble measuring the current flowing through a dc circuit, don't be frustrated. Grab some wire and make a shunt!

[1]Current through a resistor develops a voltage across that resistor. Kirchoff's Voltage Law tells us that this reduces, or *drops*, the voltage available to the rest of the circuit. Because V = I × R, this voltage is also called *IR drop*. To learn more about resistance, Ohm's Law and Kirchoff's Laws, look in the "DC Theory and Resistive Components" chapter of the 1995 or 1996 *ARRL Handbooks*. To learn more about measurement techniques, look at the "Test Procedures and Projects" chapter.

[2]Surplus meters are available from Fair Radio Sales, PO Box 1105, Lima, OH 45802-1105; tel 419-227-6573, fax 419-227-1313.

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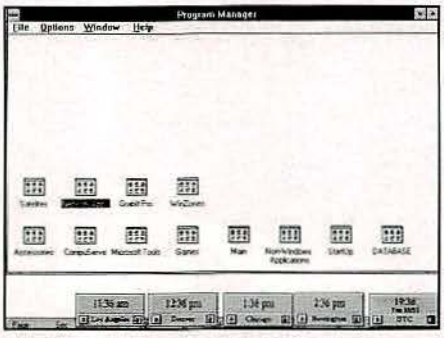
New Products

WinZones Global Time Zone Software

◊ You can have all the time in the world as close as your PC. *WinZones* by Extend Incorporated is a software package that allows you to display active clocks on your monitor while you're working with other *Windows* applications.

The *WinZones* software is extremely flexible. You can display multiple clocks on your desktop for up to 100 major cities. If the city you want isn't in the list, you can create a custom clock in seconds. For example, I created one custom clock for Newington, Connecticut and another for "UTC."

You can arrange the clocks anywhere on the screen. If a clock happens to get in the way of something you need to see, simply "drag and drop" it elsewhere using your mouse. The "always-on-top" option is available to keep the clocks in view at all times.



WinZones allows you to place active clocks anywhere on your *Windows* desktop.

In the configuration menu you can set other options such as analog or digital display, Roman or Arabic numerals, seconds display, date display, and even the colors and fonts of city names. You can also set alarms for each clock with individual alarm messages. ("Meet Paul on 14.268!")

WinZones is available in *Windows 3.1* and *Windows 95* versions. To run *WinZones*, you must own a 386 PC or higher with 4 Mbytes of RAM and approximately 1 Mbyte of available hard disk capacity.

Manufacturer: Extend Incorporated, 4847 Hopyard Rd, Suite 3218, Pleasanton, CA 94588; tel 510-484-0395, fax 510-484-0153, e-mail 74024.3574@compuserve.com. Suggested list price: $34.95.—*Steve Ford, WB8IMY*